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Urban parks provide ecosystem services by retaining metals and nutrients in soils☆

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ABSTRACT

Urban greenspaces provide ecosystem services like more natural ecosystems do. For instance, vegetation modifies soil properties, including pH and soil organic matter content, yet little is known about its effect on metals. We investigated whether the accumulation and mobility of heavy metals, nutrients and carbon is affected by plant functional types (evergreen or deciduous trees, lawns) in urban parks of varying ages in southern Finland. Plant types modified soil physico-chemical parameters differently, resulting in diverging accumulation and mobility of metals and other elements in park soils. However, the effects of plant functional type depended on park age: lawns in parks of ca. 50 y old had the highest contents of Cr, Cu, Fe, Mn, Ni, and Zn, and in these, and older parks (>100 y old), contents of most metals were lowest under evergreen trees. The mobility of metals and other elements was influenced by the amount of water leached through the soils, highlighting the importance of vegetation on hydrology. Soils under evergreen trees in young parks and lawns in intermediately-aged parks were most permeable to water, and thus had high loads of Ca, Cr, Cu, Fe, Ni, tot-P and tot-N. The loads/concentrations of elements in the leachates was not clearly reflected by their content/concentration in the soil, alluding to the storage capacity of these elements in urban park soils. Our results suggest that in urban systems with a high proportion of impermeable surfaces, park soil has the potential to store nutrients and metals and provide an important ecosystem service particularly in polluted cities.

1. Introduction

Heavy metals occur naturally in soils and are predominantly derived from soil parent material (Longhurst et al., 2004). Urban milieus, especially their soils, are further enriched with heavy metals because of anthropogenic activities, such as the combustion of fossil fuels (Wong et al., 2006; Elless et al., 2007; Yesilonis et al., 2008). Sites close to traffic routes are typically enriched with heavy metals originating from tire wear particles and weathered street surfaces (Chen et al., 2005; Salonen and Korkka-Niemi, 2007; Amato et al., 2009). As metals are often rather immobile once deposited on the soil surface, accumulation occurs (Thornton, 1991; Yong et al., 1992), which can also be detectable in plant tissues (Jumpponen and Jones, 2010). Heavy metals can come into contact with humans as suspended dust or they may be ingested in playgrounds and urban parks (Ljung et al., 2006). As a result, heavy metals and their accumulation in urban environments can adversely impact human health (Thornton, 1991; Rabito et al., 2003). Additionally, because of the high proportion of sealed surfaces, urban-derived metals can flush away via urban runoff (Valtanen et al., 2014, 2015), causing the contamination of adjacent water bodies (Davis et al., 2001).

Urban greenspaces provide important ecosystem services (ESS) (Wall et al., 2015). Evidence suggests that, besides urban green infrastructure (i.e., plants), urban soils can provide many ESS similar to non-urban soils (Pouyat et al., 2010; Setälä et al., 2014). For example, urban soils store considerable amounts of carbon and nitrogen (Franzluebbers, 2002; Pouyat et al., 2010; Edmondson et al., 2014a; Setälä et al., 2016), purify runoff water (Valtanen et al., 2015; Taka et al., 2017) and detoxify harmful substances (Lehmann and Stahr, 2007). As many of these beneficial ESS relate to the volume and quality of soil organic matter (SOM) (Lal, 2004; Allison, 2006), and because the quality and quantity of SOM is

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controlled by the type and quantity of local vegetation (Bardgett and Wardle, 2010), understanding the interactions between urban vegetation and soils is pivotal in mitigating the adverse effects of anthropogenic contamination (Acosta et al., 2014). However, because of recurring and continuous structural disturbance and contamination with various pollutants, the ability of urban soils to provide ESS may be limited. Even though some plants and soil organisms can mitigate the adverse effects of and even detoxify organic toxicants, such as polyaromatic hydrocarbons or PAHs (Reid et al., 2000; Couling et al., 2010), soil biota may be less likely to directly and efficiently reduce the harmful effects of non-biodegradable elements, such as metals. Furthermore, although urban vegetation may directly influence pollution loads by protecting against aerial deposition onto the soil (Trammell et al., 2011; Curran-Cournane et al., 2015), little, if anything, is known about its effects on metal accumulation within urban habitats.

Besides direct effects by some hyperaccumulator plants (see McGrath and Zhao, 2003) and fungi (see Colpaert et al., 2011), the plant-soil system can also indirectly mitigate the adverse effects of heavy metal contamination. Growing evidence suggests that vegetation strongly controls soil properties and biogeochemical processes in natural and urban habitats (Wardle, 2002; Bardgett and Wardle, 2010; Buol et al., 2011; Edmondson et al., 2014b; Ossola et al., 2015). For example, soil pH, %OM and pools of C and N can be influenced not only by the quantity (Pouyat et al., 2009; Livesley et al., 2016) but also by the quality of urban vegetation (Edmondson et al., 2014b; Setälä et al., 2016). Importantly, because SOM content can affect trace metal concentrations in urban soils (Brown et al., 2003; Lair et al., 2007; Pouyat et al., 2010; Acosta et al., 2014), it is possible that, by accumulating organic matter in the rhizosphere soils, plants can efficiently bind metals and thus control their mobility.

Our previous studies conducted in urban parks in southern Finland indicated that both plant functional type and park age affect soil pH, soil OM content, concentrations of soil C and N (Setälä et al., 2016) and soil microbial communities (Hui et al., 2017). However, the influence of plant functional type and park age on (i) metal concentrations and (ii) their mobility in these urban greenspaces remain unknown. Little information is available about the role of vegetation in the mobility of heavy metals in urban soils (Acosta et al., 2014), and our knowledge on the effects of plant functional types on heavy metal dynamics is virtually nonexistent. Similarly to vegetation, park age can also affect the density and composition of heavy metals in urban soils. For example, Chen et al. (2005) and Guo et al. (2012) reported that old parks have higher concentrations of Pb and Cu compared to young parks in China, while Ljung et al. (2006) found an increasing trend of an array of trace metals with the age of urban greenspaces in Sweden. These findings likely relate to the time old parks have been exposed to metal contamination. It is also possible that the increasing density of OM in park soils with park age (Golubiewski, 2006; Raciti et al., 2011; Setälä et al., 2016) increases the capacity of old soils to immobilize C and nutrients (Brown et al., 2003; Lair et al., 2007; Pouyat et al., 2010) or heavy metals (see Acosta et al., 2014).

Here we investigate whether the potential of plant functional types (evergreen or deciduous trees and lawns) to modify soil OM content, texture and bulk density is reflected in the accumulation and mobilisation/immobilisation of heavy metals, N, P and dissolved organic carbon (DOC) in urban parks of varying ages. These components were studied in the soil as well as soil leachates collected with lysimeters. We hypothesized that (1) divergent plant functional types, each producing differently decomposable litter (Ponge, 2003; Bardgett and Wardle, 2010) and thus soils with, e.g. divergent content of soil organic matter (Ponge, 2003), differ in their ability to store metals and nutrients in their rhizospheres. This is because plants producing, e.g., recalcitrant (evergreen trees) or labile (e.g. grasses and deciduous trees) litter can modify the physical-chemical-biological characteristics of urban soils differently (Edmondson et al., 2014a,b; Livesley et al., 2016; Setälä et al., 2016; Hui et al., 2017). Furthermore, we predicted that (2) soils in old parks are, due to their long history of plant-soil interactions, more modified by plants and thus differ in their ability to store and retain elements compared to young parks. We also hypothesized that (3) the mobility of metals and nutrients is influenced by plant type due to the potential alterations that the divergent plant functional groups bring forth in their rhizospheres. Finally, we predicted that (4) heavy metals are more evenly distributed among soil layers in older parks than in young parks. This is because of the longer contamination history and potential substrate homogenization over time in these older parks.

2. Materials and methods

2.1. Study area

We selected 41 parks in the cities of Helsinki (60°10′15″N, 024°56′15″E, population size of ca. 1.4 million people) and Lahti (60°59′00″N, 25°39′20″E, population size of 102 000) and 5 additional control forests (in the proximity of Lahti) in southern Finland. Climatic and edaphic information of Helsinki and Lahti can be found in Setälä et al. (2016). The urban parks, belonging to the Finnish LTSER-site network (Forsius et al., 2013), represented different ages: more than 100 years old (the oldest parks were established over two centuries ago), 50 ± 10 years old and 5–15 years old, referred to as old, intermediate and young parks, respectively (for all site localities, see https://www.google.com/maps/d/viewer?mid=195aO7WapZN03pXuzgt_sOoGMWgQ&ll=60.693374233735426%2C25.29755511966073&z=9). We selected three plant functional groups in these parks: individual evergreen (*Picea* sp. 43.3%; *Abies* sp. 20%; *Pseudotsuga menziesii* 13.3%; *Pinus sylvestris* 13.3%; *Larix* sp. 10%) or deciduous (*Tilia* x *vulgaris* 93%; *Acer platanoides* 7%) trees and lawn (mostly *Poa* and *Festuca* species with scattered herbs such as *Trifolium pratense* and *Plantago major*). Distance between the two tree types was always greater than the height of the tallest tree. The age of plants within each park age class corresponded with the age of the park, except for the young parks where trees are commonly planted as ca. 10 year old saplings at the time of park construction. As the evergreen and deciduous trees also had lawn cover within the sampled area, the design is, in essence, lawn without and with trees, either evergreen or deciduous. The ideal field design would have included 15 parks per city, represented by five old, five intermediate and five young parks, with all three plant functional groups present. However, because some parks did not include all three plant functional groups, we also selected parks with one or two plant functional groups present. This resulted in a total of 41 urban parks and 91 urban sampling locations with at least 10 replicates per park age and plant functional group (for more details, see Hui et al., 2017). Park sizes varied considerably, ranging from ca. 0.1 ha to several hectares, but with no systematic grouping of size with park age and plant functional group.

The main source of heavy metals in the larger metropolitan areas is traffic (Aarnio et al., 2001; K. Kähäri, Lahti City Environmental Services, personal information). Given the variation in park size, the proximity of soil sampling plots (see below) to adjacent roads varied between the parks. Furthermore, traffic volume (not quantified here) likely differs between roads close to the parks. However, the divergent plant functional types within a park are situated at equal distance from the main road(s) and other potential polluting sources. In the city of Lahti, parks belonging to the three